Synopsis of
Optics for the 20/20 telescope
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Abstract from paper: *We present a plan for making the optics of a 21 m telescope that builds on advances in mirror design and fabrication developed for the Large Binocular Telescope (LBT) and other large telescopes. The 21 m telescope, with a fast f/0.7 primary mirror made of only seven large honeycomb-sandwich segments and an adaptive secondary with matching segments, is much stiffer than other designs and offers simpler and more accurate wavefront control. It can be a powerful stand-alone telescope, or one of a pair that move on a circular track to achieve coherent imaging with baselines up to 120 m (the 20/20 telescope). Each segment of the 21 m primary mirror is similar to an 8.4 m LBT primary, and each segment of the 2.1 m adaptive secondary mirror is similar to an LBT secondary. The off-axis segments of both mirrors can be made with the same methods and equipment currently used at the Steward Observatory Mirror Lab, and can be polished with the same stressed-lap polishing system used for the LBT mirrors. A change in algorithm to accommodate the asymmetric surface is required, but no new hardware development is needed because the lap bending is similar to that for the LBT mirrors. Each segment can be measured interferometrically, with a combination reflective and diffractive null corrector producing an accurate aspheric template wavefront and alignment references for the segments.*

1. Introduction

This paper was written in 2003 during a time when several concepts for large telescopes (OWL and CELT) were being proposed[1,2]. For large telescopes, optical fabrication is the driving factor and telescopes much larger than 10 m will require segmented primary mirrors. It has been shown that 8 m mirrors can be fabricated and provide excellent performance. These 8-m mirrors are well understood and there is a great deal of experience in supporting them and controlling their temperature. The design discussed in this paper uses large 8.4 m segments for a 21 m primary mirror and smaller segments for an adaptive secondary.

The largest mirrors that can currently be made are 8.4 m in diameter and utilize a honeycomb structure to reduce weight and maintain stiffness. These mirrors are currently in use in the LBT and are being fabricated for the GMT (as of 2013). A major challenge for 20 – 30 m telescopes are wind forces and the honeycomb structure offers sufficient wind resistance. Another way to reduce effects of wind is to reduce the primary focal length. A telescope with a shorter overall length will be stiffer and have a lower resonance frequency. The design for the 20/20 telescope has a 21 m f/0.7 primary. Optical fabrication, testing and alignment become more critical for a fast telescope. The paper shows that current fabrication techniques are suitable for the 20/20 telescope segments and that using wavefront measurements can reduce the sensitivity of position errors when aligning the telescope segments.

Another goal of the 20/20 telescope is coherent imaging using two telescopes, which is similar to the LBT. In fact, the pupil geometry of the 20/20 telescope is similar to the LBT. The LBT has a constant separation of 14.4 m between the two telescopes. The concept for the 20/20 telescope has two telescopes on a circular track and the light is combined in the center for coherent imaging. The separation of the two telescopes can be changed, allowing for full coverage of the *u*-*v* plane.

2. Optical configuration

The design for the 20/20 telescope consists of seven 8.4 m primary segments truncated to fit together with minimal gaps. The design for the secondary mirror uses the same segment configuration on a 1/10 scale. Figure 1 shows an exploded concept view of the telescope. A goal for the telescopes is to have an adaptive secondary. This is achieved by making the optical surface of the secondary mirrors thin (1.6mm) so that actuators can push and pull on the surface to change its shape.

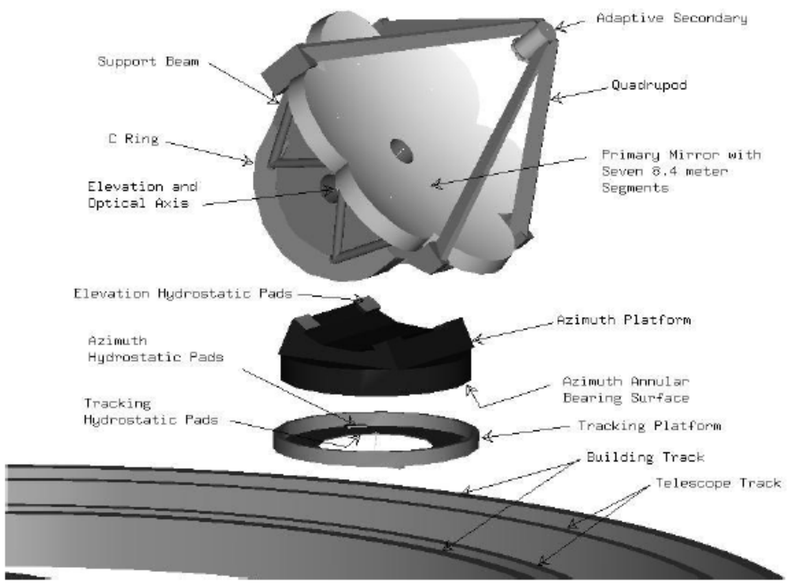

Figure 1: Exploded concept view of the telescope

3. Fabrication of the primary mirror

The primary mirror segments can be cast in the same furnace that the two LBT mirrors were cast in. In the case of the 21 m primary mirror the center segment would be truncated into a hexagon and the off axis segments would be truncated into partial hexagons. The internal honeycomb structure would be modified to have a continuous glass wall around the perimeter of the mirror. Spinning of the furnace while the glass is still molten will provide the overall curvature of the mirror surface. In the case of the off axis segments an accurate surface shape from the furnace is not necessary. The off-axis segments will have an extra 19mm of aspheric departure that will be removed using a numerically controlled mill. For the central segment the cutting wheel follows a parabolic path while the mirror is rotated about its axis. The wheel will have additional radial motions for the off-axis segments.

After the mirrors are shaped with the mill they are sent for a final polishing. The main difficulty with polishing an aspheric surface is being able to keep the tool in constant contact with a surface whose curvature changes from point to point. However, the polishing tool at the Steward Observatory Mirror Lab was designed specifically for highly aspheric surfaces. The stressed lap polishing tool constantly changes shape as it moves across the mirror surface. Actuators in the polishing tool ensure that the tool always matches the local shape of the mirror surface.

Variations in curvature across the mirror surface dictate the amount of bending required in the lap and this is the limiting factor in polishing a mirror. The segments for the 20/20 mirror have 13 times the asphericity of the LBT mirror, but the required bending in the lap is not that much greater. This is because the curvature variations in the off-axis segments are only slightly larger than those in the LBT mirror. The majority of the asphericity in the off-axis segment is in the form of astigmatism and coma which does not require large changes in curvature of the lap. The curvature variations can be expressed in mathematical form by the derivative of curvature with respect to mirror position. An aspheric surface can be represented as the departure from a spherical surface as

$$z = \frac{1}{48R^3}(6r_m^2 - 6r_m^2 r^2 + r_m^4),$$

where R is the radius of curvature, r_m is the physical radius of the mirror and r is the radial coordinate on the surface. The third derivative of z(r) is the derivative of curvature and its maximum value is $\frac{3}{16}f^{-3}D^{-2}$, where f is the f-number of the mirror. This shows that a large diameter mirror with a fast f-number can have reasonable curvature variations without increasing the difficulty of polishing.

After the mirror is polished it needs to be tested and this presents another challenge for large off-axis mirrors. A typical way to measure the surface of the mirror is to use a null corrector. A null corrector creates a wavefront that is the same shape as the surface being measured. The null corrector uses a series of refractive, reflective or diffractive optics to convert a planar or spherical wavefront to the desired aspheric shape. Since the parent of the off-axis segments is a 23 m f/0.65 a single stage null corrector would be too large to manufacture to the correct tolerances. A solution to this is to use a two stage null corrector comprised of a refractive or reflective first stage and a diffractive second stage. The first stage could be comprised of two spherical mirrors which create the correct low-order shape and the second stage could be a computer-generated hologram which corrects the residual high-order asphericity. A system such as this would provide the correct aspheric shape and the off-axis segments could be measured to the desired accuracy.

4. Secondary mirror fabrication

The segments for the secondary mirror are designed to match the primary to a scale of about 1/10. Since the secondary will be adaptive the segments will require a thin surface shell so that actuators on the back can achieve the desired surface figure. In this case, the main concern when polishing the mirror is not the large-scale surface figure, but small-scale surface errors. The stressed-lap polishing can achieve the required 10nm surface error on small scales and the actuators can correct the large-scale surface figure. The thin shell on the mirror surface is a concern for polishing, but experience gained from the MMT and LBT secondaries has produced methods to polish such mirrors. One method to alleviate problems with the shell during polishing is to polish the surface then grind away the rear surface to the desired thickness. Deformations caused by the removal of glass and internal stress should be small enough that the actuators can correct them.

Measurement of the secondary could be done using methods developed for the 1.7 m f/5 MMT secondary. This would be a full aperture measurement using a profilometer to measure the surface to 50nm rms accuracy and then using a full-aperture interferometric test to make the final measurements. In the past, full aperture measurements have been troublesome due to the difficulty in fabricating a 1.7m test plate. Testing the secondary segments individually with the same type of two-stage null test as the primary is a favorable method.

5. Demonstration of off-axis figuring and measurement

A 2m diameter stressed-lap polishing machine will be used to figure a 1.8m f/2.7 segment which will be lighweighted. This segment is roughly a ¼ model of the primary segments in the 20/20 telescope. The demonstration segment will be tested using the holographic testing and alignment techniques described earlier.

6. Manufacturing plan

The 8.4 m segments would be made at the Mirror Lab utilizing 2 8.4 m capacity machines, with one used for generating and the other for polishing. The production time is expected to be 9 months per segment which means that 7 segments plus one spare can be produced in about 7.5 years. In order to make two 21 m telescope a second facility must be utilized to ensure timely production of the segments.

7. Conclusion

Several methods have been developed to produce a 21 m telescope with 8.4 m segments and a 2.1m adaptive secondary. Current methods and technology can be used for manufacturing the segments and new techniques for measuring and aligning aspheric mirror segments are being developed. The Mirror Lab can produce enough segments for one telescope in about 7.5 years, but another facility would be need to produce enough segments for two telescopes.

References

1. P. Dierickx, R. Gilmozzi, “Progress of the OWL 100-m Telescope Conceptual Design”, in *Telescope Structures, Enclosures, Controls, Assembly/Integration/Validation, and Commissioning*, ed. T. Sebring, T. Andersen, Proc. SPIE 4004, p. 290 (2000).

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